ENGELMANN SPRUCE REGENERATION PRACTICES IN THE ROCKY MOUNTAINS

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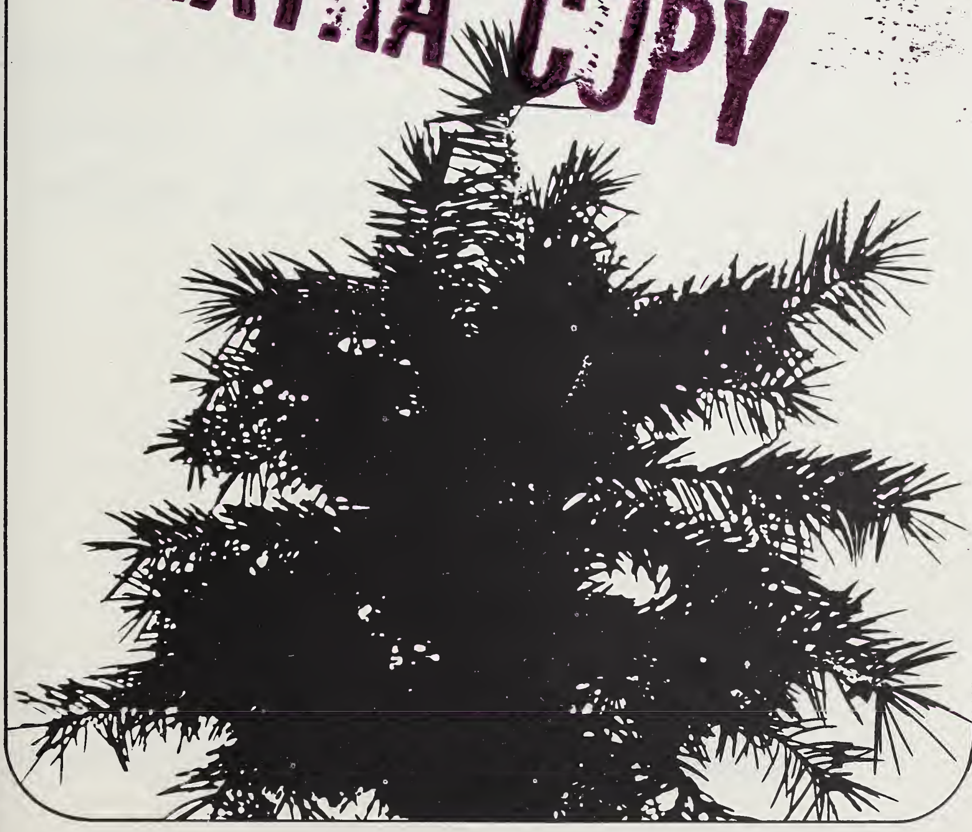

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Engelmann Spruce Regeneration Practices in the Rocky Mountains

Arthur L. Roe, Robert R. Alexander, and Milton D. Andrews[1]

INTRODUCTION

Forest managers, particularly in the Intermountain and central Rocky Mountain areas, are concerned with the difficulty of obtaining natural regeneration on spruce clearcut areas. In one research study in Colorado, mountain spruce regenerated slowly but ultimately well after clearcutting small areas (Alexander 1963). Because large-scale clearcuttings are of relatively recent origin in the spruce-fir type in all regions, natural regeneration following cutting has not been fully appraised. In some situations and under some conditions, spruce has been found to be reproducing well on larger cutovers in the central and Intermountain areas; on other cutovers, new spruce reproduction has been virtually nonexistent (Roe and Schmidt 1964, Alexander 1966, 1968).

Results of attempts to establish spruce artificially on cutover areas have been variable. Planting has been successful in the northern Rockies on well-prepared sites. Attention to adequate site preparation and to the quality, care, and handling of planting stock have produced encouraging results in other areas. Direct seeding, however, has not been generally acceptable. To keep the land productive forest managers urgently need solutions to problems of natural and artificial regeneration.

The purposes of this report are to (1) bring together in one place pertinent information, based on both experience and research, on spruce regeneration requirements and limitations and (2) provide some preliminary guides to aid the land manager in developing regeneration practices for restocking spruce stands.

The information on spruce regeneration requirements and limitations—and therefore the guides—are necessarily *broad* in scope and *preliminary* in nature. We have attempted to put together a framework of experience and knowledge which will aid the land manager in developing more specific guides for *his* local situation and policy. Since natural regeneration in Engelmann spruce is less well understood than planting, we have placed greater emphasis on natural restocking.

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BACKGROUND INFORMATION

NATURAL RANGE

Engelmann spruce (*Picea engelmannii* Parry), usually in association with subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), forms one of the most widely distributed forest types in North America (fig. 1).

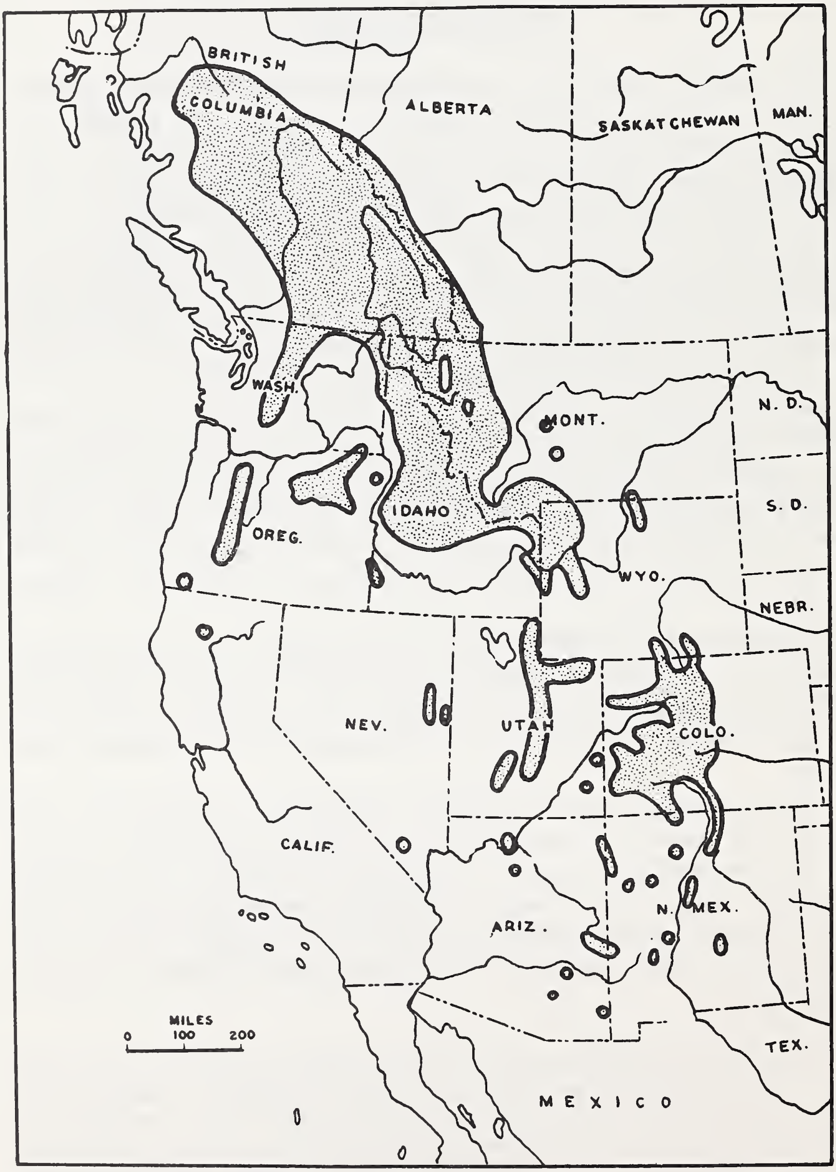

***Figure 1.*—Natural range of Engelmann spruce.**

Growing at high elevations and in rough terrain, spruce is one of the most inaccessible and least known silviculturally of the commercial timber trees in the Rocky Mountains. However, spruce forests are potentially very productive, despite cold temperatures and short growing seasons, because the high mountains are humid and well watered.

STAND CONDITIONS

Mature Engelmann spruce in association with subalpine fir forms a relatively stable forest vegetation throughout much of the central and southern Rockies (Society of American Foresters 1954). Such stands are not easily displaced by other vegetation except as a consequence of disturbance by logging, fire, or insect and disease attack. In the Intermountain and northern Rockies, Engelmann spruce is likely to diminish in climax forests, being succeeded principally by subalpine fir. Some disturbance such as windfall or fire is necessary to expose mineral soil before spruce seedlings can become established in climax associations (Daubenmire and Daubenmire 1968).

Complete removal of a spruce stand by fire, clearcutting, or insect attack results in drastic environmental changes that tend to favor establishment of more shade-intolerant species such as aspen (*Populus tremuloides* Michx.), lodgepole pine (*Pinus contorta* Dougl.), and western larch (*Larix occidentalis* Nutt.). Shrubs and other lower growing vegetation may move in to occupy the sites and preclude the establishment of tree species for many years unless tree seed falls soon after the disturbance, or the site is artificially reforested.

Unlike most true climax forests, few spruce forests have been free of catastrophic disturbance long enough to develop an all-aged structure. Some spruce stands are even-aged or even-sized; others are two- or three-storied (LeBarron and Jemison 1952). This indicates that desirable spruce forests can be grown under even-aged management.

The structure of old-forests is frequently nearly pure spruce in the overstory with fir predominating in the understory. In Colorado and Wyoming, spruce commonly makes up from 70 to 90 percent of the overstory basal area, and subalpine fir, from two-thirds to three-fourths of the advance understory growth (Oosting and Reed 1952). This structure has developed because, under natural conditions, spruce becomes readily established only on mineral soil and rotten wood seedbeds, whereas fir is not exacting in its seedbed requirements. Furthermore, although spruce seedling survival is better in the shade than in the open, spruce cannot compete with fir under the low light intensities commonly associated with dense spruce-fir forests. On the other hand, once established, spruce lives longer than fir (Alexander 1958).

As with most underdeveloped forest types, spruce-fir forests have a serious imbalance in age-class distribution. The largest proportion of stocked area is in sawtimber-sized stands, the smallest, in seedling and sapling stands (Miller and Choate 1964, Roe and James 1958). Furthermore, most of the sawtimber-sized stands are overmature and ready for harvest.

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HABITATS

Habitat conditions are diverse in the spruce-fir forest zone, both within and between regions of the Rocky Mountains. Therefore, ecologists and foresters have classified spruce-fir forests by ecological habitat types, stand structure, topography, and geographic location. But because these classifications are limited geographically or have differing criteria, their broad application is limited.

Daubenmire and Daubenmire (1968) developed a habitat-type classification of forest vegetation in the northern Rocky Mountains. The core area of this study lies east of the San Pail and Kettle Rivers in Washington, and north of the Salmon-Clearwater River Divide in Idaho. Engelmann spruce is classified as either seral or climax in 10 different forest associations. Subalpine fir is the dominant climax species in four of the associations.

Associations in which spruce is climax are:

1. *Abies lasiocarpa-Vaccinium scoparium* (grouse whortleberry)—all slopes, mostly upper elevations. This association extends north, east, and south of the core area. It has been observed in British Columbia (Illingsworth and Arlidge 1960), Montana, southern Idaho, and Utah. It is also common in the central Rocky Mountains (Oosting and Reed 1952).
2. *Abies lasiocarpa-Pachistima myrsinites* (boxleaf myrtle)—lower slopes of the spruce-fir zone. This association is common in southeastern Idaho and western Montana, and has been observed as far south as Colorado.

Associations in which spruce is seral are:

1. *Abies lasiocarpa-Xerophyllum tenax* (beargrass)—upper south- and west-facing slopes. Spruce weakly represented.
2. *Abies lasiocarpa-Menziesia ferruginea* (rusty skunkbrush)—upper north- and east-facing slopes. Spruce weakly represented.
3. *Abies grandis-Pachistima myrsinites* (boxleaf myrtle)—warm, dry, mainly mid-south-facing slopes with good drainage.
4. *Thuja plicata-Pachistima myrsinites* (boxleaf myrtle)—moderately warm, dry, mainly south-facing slopes with good drainage.
5. *Thuja plicata-Athyrium filix-foemina* (ladyfern)—moderately warm, moist, mainly south-facing slopes with poor soil drainage.
6. *Thuja plicata-Oplopanax horridum* (devilsclub)—cool, wet, mainly north-facing slopes with poor soil drainage.
7. *Tsuga mertensiana-Xerophyllum tenax* (beargrass)—upper south- and west-facing slopes. Spruce weakly represented.
8. *Tsuga mertensiana-Menziesia ferruginea* (rusty skunkbrush)—upper north- and east-facing slopes—limited distribution.

The best spruce sites in the northern Rocky Mountains are found in the *Menziesia, Pachistima,* and *Oplopanax* associations. Moisture in these associations is not as limiting to spruce regeneration as in the other associations, but understory vegetation is dense and aggressive; it may invade cutover areas and compete vigorously with spruce reproduction. The *Xerophyllum* associations present the most difficult problems for spruce regeneration because rapid drying

of the soil surface layers reduces early seedling survival (Daubenmire and Daubenmire 1968). These associations, plus the *Vaccinium* association, are the poorest spruce sites in the northern Rockies. Some of these habitat types may have broader application than the core area, but extrapolation must await studies elsewhere.

Roe and Schmidt (1964) classified the spruce-fir forests of the Intermountain Region into the following three units on the basis of their differing ecological and management problems:

1. *Northern*—All spruce in southwestern Idaho south of the Salmon River. Lodgepole pine is a major component of the spruce-fir type.
2. *Transition*—All spruce in southeastern Idaho, western Wyoming, and eastern Utah south of the Uinta Mountain Range. It is considered transition because lodgepole pine diminishes in importance from north to south, and aspen tends to replace it.
3. *Southern*—The spruce in southeastern Utah south of the Uinta Mountains. Aspen is a major associate of spruce.

Spruce forests in the Northern Unit grow at the lowest elevations (6,000 to 9,000 feet) and on the best sites in the region. Natural regeneration appears to be more aggressive than on the other two units. The spruce forests in the Transition Unit grow at elevations between 7,500 and 10,500 feet. Sites are not as good as in the Northern Unit, and natural regeneration problems are more difficult. The spruce forests in the Southern Unit grow on high plateaus at elevations between 9,000 and 11,500 feet. Sites are the poorest in the region, and natural regeneration is most difficult.

In the central Rocky Mountains, the spruce-fir type has been divided into the following three subregions on the basis of topography, soil, and precipitation pattern (Alexander 1967b):

1. *Mountain spruce*—All the spruce forests in the mountainous portions of Colorado (except southwestern Colorado) and southern Wyoming.
2. *Mesa spruce*—All the spruce forests in the plateau region of western Colorado.
3. *Southwestern spruce*—The spruce forests of the high mountains of southwestern Colorado, principally on the San Juan National Forest but including portions of the Rio Grande, Gunnison, and Uncompaghre National Forests.

The distinguishing characteristics of the mountain spruce forests are wide altitudinal range (9,000 to 11,500 feet), poor to average sites, light-textured soils, and a ground cover of grouse whortleberry. Ground cover is altered little by cutting and does not compete severely with tree seedlings. Mesa forests are characterized by limited altitudinal range (9,500 to 10,500 feet), average to good sites, heavy-textured soils, and a ground cover of herbaceous vegetation. Cutover areas are invaded rapidly by rank growth of herbs followed by grasses and sedges; all compete intensely with seedlings. Southwestern spruce forests include all combinations of elevation, soil, and site found in mesa and mountain forests. The distinguishing characteristic is the precipitation pattern. Prolonged late spring and early summer drought limits success of natural spruce regeneration.

Land managers need a natural classification of the spruce-fir forest zone upon which they can base management practices, identify problems, and extrapolate research results. Such a classification should have broad applicability, and be based on sound ecological principles such as the habitat-type classification developed by Daubenmire and Daubenmire (1968) in the northern Rockies.

INSECT HISTORY

Engelmann spruce is especially susceptible to bark beetle (*Dendroctonus obesus* Mann.) attacks. Epidemics have occurred throughout recorded history, but in recent years spruce beetles have devastated Rocky Mountain stands. In Colorado, a heavy blowdown on the White River Plateau in 1939 initiated a spruce beetle population buildup that killed nearly 4.5 billion board feet of timber before the epidemic was finally controlled in 1952 (Wygant 1958). A similar but less widespread outbreak followed a heavy blowdown in southwestern Colorado; it lasted from 1950 through 1955 (fig. 2). A severe blowdown

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Figure 2.—**Engelmann spruce blowdown, San Juan National Forest, Colo.**

in spruce in Idaho and Montana in 1949 led to an epidemic which required salvage cutting of 2.5 billion board feet of timber before the beetle population was reduced to a tolerable level in 1957 (Roe and James 1958).

Although bark beetle attacks have been largely associated with extensive blowdowns over large areas, cull material left on the ground after cutting and scattered windfalls that may occur after partial cutting can also provide breeding places for beetles.

CUTTING HISTORY

Limited areas of the original spruce-fir forests were logged in the late 1800's to provide fuel, lumber, and timbers for the early mining camps in the West. Cuttings on the National Forests date back 50 years or more, but until the 1950's, only small quantities of timber were harvested. Cutting has accelerated rapidly since.

Most cuttings in spruce-fir forests before 1950 in the northern and central Rocky Mountains and before 1958 in the Intermountain Region were of a type that were collectively called "partial cuttings." They ranged from removal of a few individual trees to removal of all the larger, more valuable trees in the stand. Seedbed preparation was limited to the disturbance created by logging, and slash was untreated or lopped. Much of the early skidding was done with horses. In the 1950's harvesting shifted to clearcutting followed by slash disposal that thoroughly disturbed the seedbed. The common practice was to cut in large blocks, patches, or wide strips. Slash and cull material were then either broadcast burned, dozer-piled, or windrowed and burned. That practice resulted in almost complete cleanup of cutover areas. Hazards from fire and insect attacks were reduced and mineral soil was exposed, but the removal of all slash, cull material, and residual trees left the seedbeds devoid of shade, thereby creating a difficult microenvironment for the establishment of either natural or artificial regeneration.

NATURAL REGENERATION REQUIREMENTS

A supply of viable seed, a suitable seedbed, and an environment compatible with germination and seedling establishment are the basic elements necessary for successful natural regeneration. If one of these elements is missing, regeneration fails (fig. 3).

SEED SUPPLY

Production

Few studies of Engelmann spruce seed production are recorded for the Rocky Mountain Regions. Boe (1954) analyzed Rangers' seed records in Montana between the years 1908 and 1953. He reported data separately for the areas east and west of the Continental Divide. West of the Divide, 22 crops observed during the 45-year period were rated as 5 good, 8 fair, and 9 poor. East of the

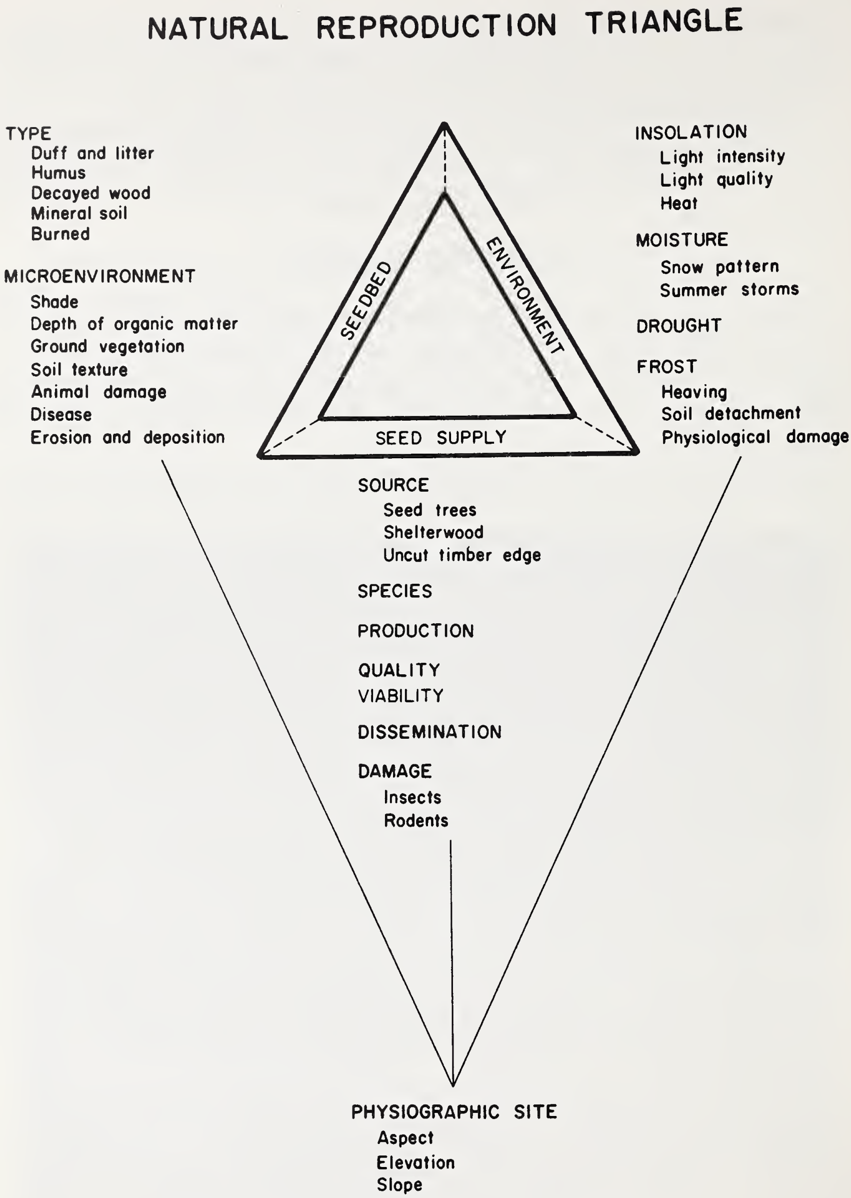

***Figure 3.*—Factors influencing seedling establishment.**

Divide, seed production was considerably poorer. Only 2 good, 4 fair, and 15 poor crops were reported for a 21-year period. Throughout Montana, 1926 and 1952 were exceptionally good spruce seed years, but only the 1952 crop was heavy throughout the Rockies. In a recently completed study in Colorado, Alexander (1969) found that annual seed production on one area averaged only

32,100 sound seeds per acre during the period 1956–65. He reported only 1 good and 2 moderate crops during the 10-year period of observation. Seed production in other years was a failure. Infrequent seed crops means that natural reproduction cannot be expected every year.

Dissemination

Spruce seed is light and disperses long distances. Squillace (1954) found that significant quantities of seed (60,000 sound seed per acre) were dispersed as far as 600 feet from the timber edge in a large, spruce clearcut block in western Montana. However, this wide dispersal occurred only during a "bumper" (1952) seed year.

Roe (1967) showed that spruce seed dissemination on three areas in the Intermountain Region followed an exponential relationship as it diminished from timber edge into openings. Seed was dispersed in significant quantities (nearly 5 percent of total) as far as 660 feet where there was a heavy seed source (193 square feet of basal area in Engelmann spruce seed trees 10.0 inches d.b.h. and larger) around the perimeter of the opening. Lighter seed sources, 70 square feet basal area or less, dispersed fewer seed for shorter distances. In such cases, smaller openings are required to insure an adequate amount of seed on all parts of the cutting. If cuttings are larger, areas beyond the reach of adequate natural seeding must be planted or seeded (fig. 4).

Alexander (1969) found the seed dissemination pattern in Colorado similar to that observed by Roe (1967). Furthermore, the dispersal pattern suggested that seedfall into clearcut openings was influenced by the direction of prevailing winds.

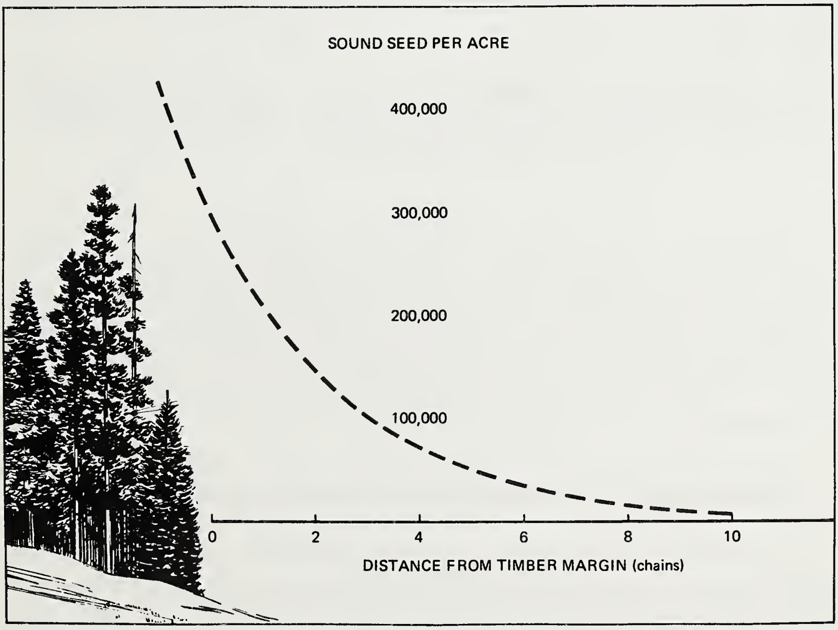

***Figure 4.*—Seedfall in relation to distance from seed source for stands of average basal area.**

However, the direction of dispersal winds has been too variable throughout the spruce type to show any definite patterns.

Knowing that seed may be dispersed as far as 660 feet from the source is not enough. Great quantities of seed will not stock a harsh or incompatible environment. The effective seeding distance, defined as the distance over which sufficient sound seed is dispersed to stock an area to an acceptable level under prevailing conditions, is more meaningful than mere seed dispersal distance.

Studies in the Intermountain Region show that an effective seeding distance of 660 feet is possible on northerly aspects with nearly 200 square feet of basal area in seed trees in the uncut timber edge (Roe 1967). Effective distance on south aspects (harsher environment) may be as low as 260 to 400 feet. Effective seeding distance for a lesser seed source, 70 square feet of basal area or less, may be as low as 0 to 200 feet on northern slopes and 0 on other aspects. The longer the favorable seedbed exists, the greater the effective distance.

Source

Several ways of providing a seed source—leaving scattered seed trees, partial cuttings, and uncut timber around the margins of clearcut blocks, strips, or patches—have been tried in spruce forests with variable success.

One of the significant considerations in the kind of seed source to leave is resistance to windthrow. Alexander (1964, 1967a), studying blowdown around the margins of clearcut units in Colorado, identified many situations and conditions where windfall risks were above and below average. In a very old cutting on the Kaniksu National Forest in northern Idaho, Roe and DeJarnette (1965) found that small seed-tree groups and 1-chain-wide strips suffered such severe, early windthrow that they were not a reliable seed source.

The Kaniksu study also showed that the surrounding timber edge contributed seed for reproduction in a 660-foot peripheral strip around a large patchcutting. On the same area, a partial cutting that left about 6,000 board feet per acre on a deep soil in a sheltered location also provided a good seed source.

Viability

If the seeds are properly stored, viability of Engelmann spruce is rated both good (average germinative capacity about 69 percent the first year) and persistent (average germinative capacity as high as 30 to 50 percent after 5 years). Spruce does not normally require pretreatment to break dormancy. Under natural conditions, seed overwinters under the snow and germinates the following spring (Alexander 1958).

ENVIRONMENTAL FACTORS AFFECTING GERMINATION

The seedbed is one of the keys to spruce germination. Germination is often good on mineral soil and burned seedbeds where a constant supply of moisture is available (Day and Duffy 1963, Day 1964, Roe and Schmidt 1964). The natural forest floor or litter is generally a poor seedbed. Some writers point out

that germination may be high on decayed wood, but this good initial germination is offset by heavy seedling mortality when the decayed wood dries out.

The effectiveness of the seedbed is influenced by such factors as shade, precipitation, soil texture, and soil moisture. Although dead shade is beneficial because it reduces temperature and evaporation and conserves soil moisture, low temperatures may delay germination in the spring. By the time seedbeds are warm enough for germination, they may be too dry. Germination can also be delayed by summer drought. Ronco (1967) found that many spring sowings failed because early summer drought delayed germination until late August. The late-germinating seedlings were unable to harden off before the onset of fall and winter weather. The study also showed that germination followed definite storm periods.

Roe [2] found striking differences in germination between two soil types in western Montana. Seeds were sown in the spring on two areas: one was a droughty, sandy soil; the other was a black, moderately heavy loam soil that retained a high moisture content through the season. More than nine times as many seedlings germinated on the heavier soil. Apparently, rapid surface drying limited moisture for germination on the droughty, sandy soil.

Barr (1930) and Smith (1955) reported that available soil moisture was the most critical edaphic factor in spruce germination in British Columbia, especially on duff and mineral soil seedbeds. Mineral soil often retained sufficient moisture for germination, but even when duff moisture stayed above the wilting point, seeds in the duff were unable to absorb enough moisture to germinate.

In Logan Canyon, Utah, spruce germinated most readily in protected areas where large snow accumulations melted slowly in the spring. The moisture regime on those seedbeds was favorable in the spring when suitable temperatures for germination were reached. (Daniels [3]).

ENVIRONMENTAL FACTORS AFFECTING ESTABLISHMENT AND SURVIVAL

Management of regeneration on spruce cutover areas requires discerning consideration of the influence of environmental factors. Spruce stands that have developed over many decades, and often through several successional stages of community development, have approached an equilibrium with the environment. The plants themselves have modified the environment. When the protective influence of the mature stand is removed, some environmental factors become limiting to spruce seedling establishment and survival.

Manipulation of the environment to create favorable microhabitats can aid seedling establishment and survival. Seedbed preparation, for example, can modify some limiting environmental factors sufficiently to enable seedlings to survive.

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[2] Data on file at Intermountain Forest and Range Exp. Sta., USDA Forest Serv., Ogden, Utah.

[3] Personal discussion with Dr. L. Daniels, Utah State University, Logan, Utah.

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Seedbed

The effectiveness of seedbed treatment on seedling establishment and survival was demonstrated in northern Idaho.[4] Five seedbed conditions were tested in clearcut blocks: (1) No treatment, natural forest floor; (2) prescribed burn; (3) 25 percent of the area scarified by bulldozer; (4) 50 percent scarified; and (5) 75 percent scarified.

Five years after the study was started, spruce seedings were present on only 12 percent of the milacre plots examined on the natural forest floor, but they were found on 53 percent of the plots in the prescribed burn area, and on 23, 55, and 63 percent of the plots on the areas scarified 25, 50, and 75 percent, respectively (fig. 5).

Day and Duffy (1963) and Day (1964) reported best seedling establishment on decayed wood on the Crowsnest Forest in southwestern Alberta, but success there was associated with moist sites.

The Intermountain Region spruce regeneration survey showed that mechanically exposed mineral soil was superior to all other types of seedbed for seedling establishment and early survival (Roe and Schmidt 1964) (fig. 6). Decayed wood and natural forest floor were the poorest seedbeds, except in south-central Utah. There, no stocking whatsoever was found on the burned piles or windrows, and disturbed duff was very poorly stocked. The burned seedbeds were com-

[4] Personal correspondence with Glenn H. Deitschman, USDA Forest Serv., Forestry Sciences Laboratory, Moscow, Idaho.

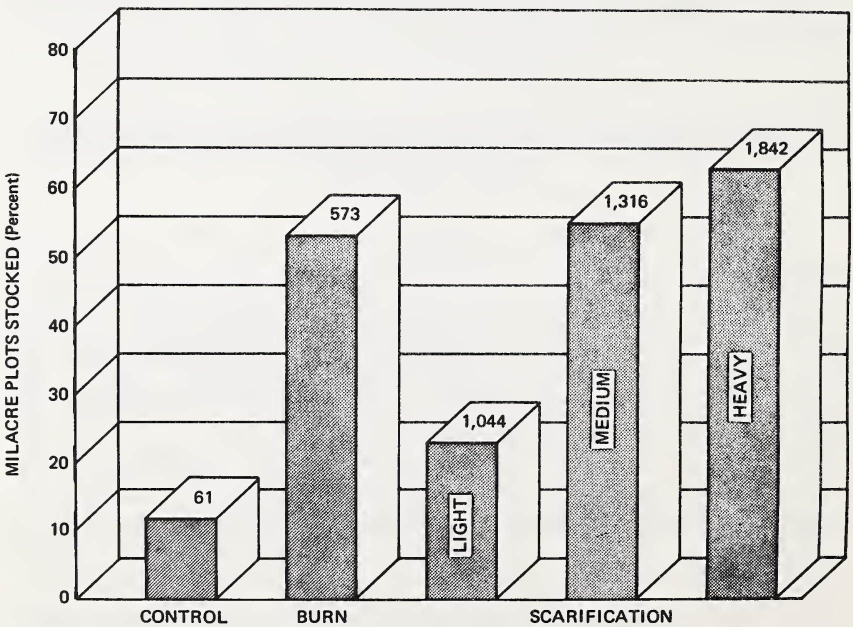

Figure 5.—Percent of milacres stocked to spruce in relation to different seedbed treatments. (Numbers on the tops of the bars are trees per acre.)

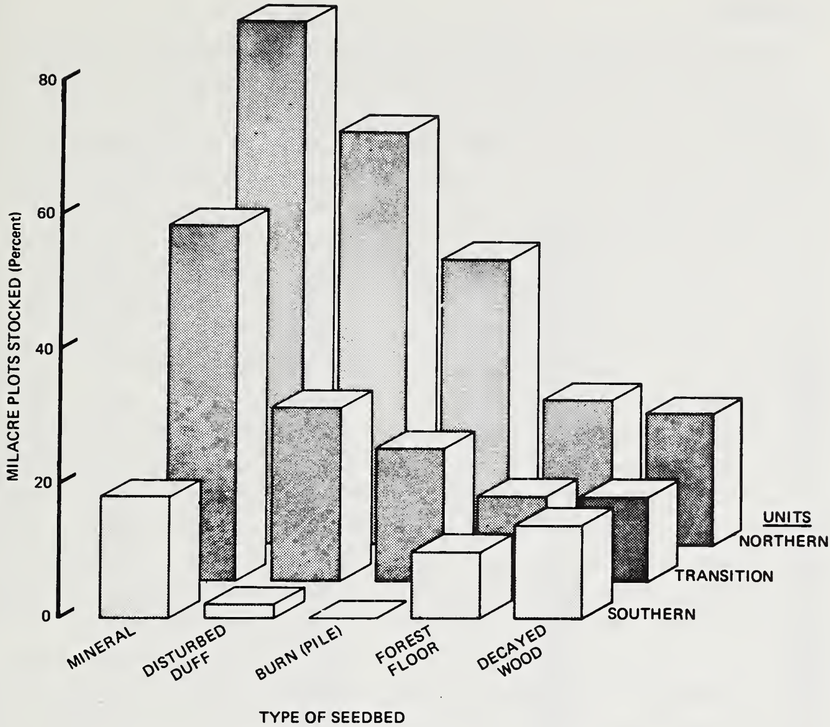

***Figure 6.*—Stocking to spruce seedlings in relation to seedbed type.**

prised of loose ash layers several inches deep. Burning the concentrations of fuel caused such great heat that large rocks were fractured. Observations on the Coram Experimental Forest in Montana have shown that it may take 5 years or longer before such heavily burned spots will support plants.

The best success in artificially establishing spruce on the Payette National Forest [5] was attained by planting 2–0 spruce seedlings in furrows plowed with a Holt plow. More 3-year-old seedlings survived in the furrows than in either dozer-piled and burned areas or in hand-scalped spots. Furthermore, trees survived substantially better in locations where the soil in the furrows remained visibly moist throughout the hottest days in the season than where soil was visibly dry. The report points out that before treatment, a very dense accumulation of plant roots formed a compact layer in the upper 6 inches of the soil. Furrowing removed the root mat and placed the seedling roots from 1 to 4 inches below this layer.

Climate

Engelmann spruce grows in a cold, humid climate characterized by extremes (Alexander 1958). Because the climate does vary so widely, some of the extremes may limit regeneration success.

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[5] Dahlgreen, Allen K. 1966. Unpublished report of an administrative study on file in the Div. of Timber Manage., Intermountain Reg., USDA Forest Serv., Ogden, Utah.

Insolation

Three facets of insolation—light intensity, light quality, and heat—are important to seedling survival at high elevations. Insolation is known to be high at the elevation where spruce grows. Kimball (1936) showed that solar radiation ranged from about 1.2 cal./cm^2/m. at 1,000 feet elevation to approximately 1.5 or 1.6 at 10,000 to 11,000 feet. Considerably higher values have been recorded in the high Colorado mountains by Spomer,[6] and Gates and Janke (1966). They found radiation frequently was 2.20 cal./cm^2/m. on a clear day with scattered cumulus clouds. On cloudless days, Spomer (ibid.) reported daily and mean weekly maximums of about 1.9 cal./cm^2/m. throughout the summer. Although radiation above timberline may exceed the solar constant of 2 cal./cm.^{2}/m. because of reflected light, maximum air temperatures rarely reach 75° F. at 10,000 feet in the Rockies.

The Rocky Mountain Station is working on the effect of light intensity as it relates to spruce seedling mortality. Results (Ronco)[7] indicate that high light intensity (visible light can be as high as 16,000 foot-candles at 10,000 feet elevation, and remain as high as 13,000 foot-candles from just after sunrise to just before sunset) is one of the factors contributing to the high mortality of open-grown seedlings. Ronco (1961) reported that mortality was reduced by shading planted seedlings in the field. Ronco (ibid.) also found that photosynthesis was higher for shaded than unshaded seedlings (fig. 7). He suggests that solarization—a phenomenon by which high light intensity inhibits photosynthesis—leads to irreversible tissue damage and subsequent death of open-grown seedlings.

High temperatures associated with high light intensity heat the soil surface and increase water losses from both seedlings and soil by increasing transpiration and evaporation. Death, especially among first-year seedlings, may occur from either drought or stem girdling.

Smith (1955) reported soil surface temperatures in British Columbia well in excess of lethal levels for spruce seedlings, particularly on burned seedbeds. Although maximum air temperatures rarely exceed 75° F. in the spruce zone of the Intermountain and central Rockies, lethal temperatures probably are reached at the soil surface. At lower elevations where spruce grows in western Montana, soil surface temperatures exceeded 160° F. on gentle, north slopes several times during the summer season.[8] Early shade protection aided survival of newly germinated seedlings in this study. Thirty to fifty percent of the seedlings were lost to heat girdling on unshaded plots compared to only 10 percent on shaded plots.

Dead shade that conserves moisture and reduces temperature and light in-

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[6] Spomer, G. E. 1962. Physiological ecology of alpine plants. Ph. D. dissertation. Colo. State Univ., Ft. Collins, Colo.

[7] Ronco, Frank. Manuscript in preparation. The influence of high light intensity on the survival of Engelmann spruce, Study No. FS–RM 1201.14. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo.

[8] Op. cit., see footnote 2.

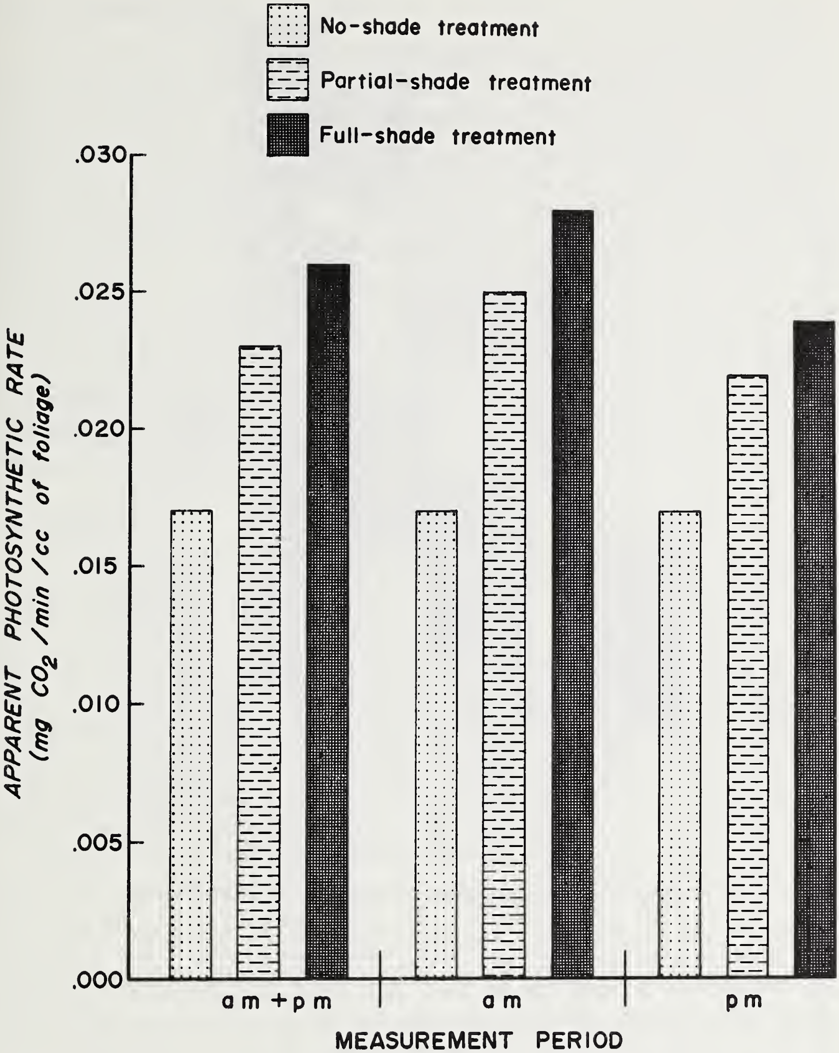

Figure 7.—**Apparent photosynthesis of shaded and unshaded 4-year-old spruce seedlings.**

tensity—whether "topographic shading" caused by unevenness in the seedbed surface or a direct shield to the sun's rays such as stumps or logs—creates an improved microenvironment for seedling survival. Roe and Schmidt (1964) found more seedlings were established in shade cast by humps, edges of depressions, sticks, logs, stones, and other nonliving material than in other microenvironments (fig. 8).

Quality is another aspect of light important to seedling development and survival. There is more ultraviolet light at high elevations, and ultraviolet light

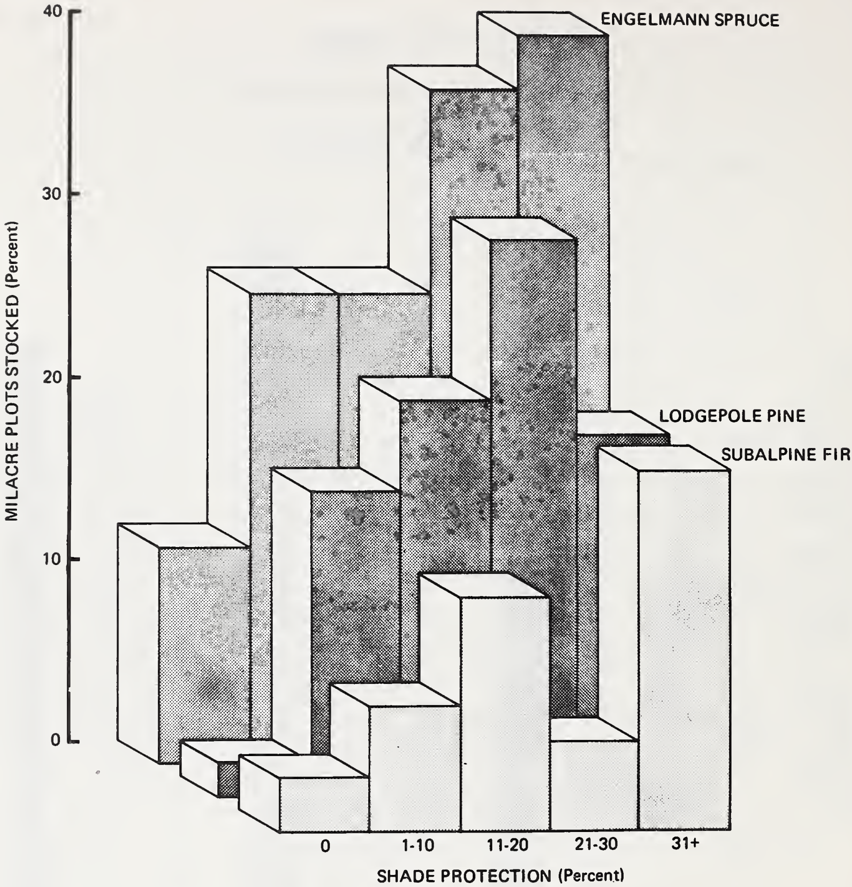

Figure 8.—**The effect of dead shade on seedling establishment.**

has been shown to have harmful effects upon some plants (University of Idaho 1963). The effect of light quality on spruce at the higher elevations is unknown, but since ultraviolet light can have a dwarfing effect on some plants, it may reduce both root and top growth of seedlings and make them more subject to drought.

Summer Storms

The frequent summer storms of the Intermountain and central Rocky Mountain regions are not always beneficial. The moisture provided by those storms, if well distributed through the growing season, enables young seedlings to survive while their root penetration is still shallow. But many of these storms are so intense—Ellison (1954) reports storm intensities of nearly 3 inches per hour for 5 minutes in Utah—that much of the moisture runs off, especially from bare soils. Soil movement on unprotected seedbeds buries some seedlings and uncovers the roots of others.

Frost

The growing season is short at 10,000 feet elevation in the Rocky Mountains. The average frost-free period is less than 60 days, and frost may occur any month of the year (Alexander 1958). The combination of warm days and cold nights during the snow-free period is conducive to frost heaving. Spruce seedlings were observed to frost heave on the margins of grass clumps and other vegetation in the spruce regeneration survey of the Intermountain Region (Roe and Schmidt 1964). Frost heaving is especially prevalent in heavy soils with a high clay content.

Physiological damage to seedlings may also result from unseasonable frost. Early in the growing season, while tissues are succulent and free water is prevalent, frost may injure or kill the shoots. Ronco (1967) has recorded frost damage every year since 1957 in Colorado. In some years damage was minor, but in others all new shoots on exposed seedlings were killed. Death of new shoots from frost was nearly eliminated by shading the seedlings.

Drought

In the northern Rockies, summer drought is a serious threat to spruce seedling survival, especially during the first growing season (Smith 1955, Haig et al. 1941). In one instance, an entire seeding of Engelmann spruce on silt loam soils, near Lindberg Lake in western Montana, was killed by drought during the last week in August and the first week in September when soil moisture averaged 5 to 10 percent below the wilting point (15 atmospheres). Since spruce seedling roots penetrate slowly, they often do not keep pace with soil drying during the summer drought. Any prolonged period of drought during the seedling's first growing season is critical, therefore in the northern Rockies.

Ellison (1954) reported that average annual precipitation in the subalpine zone of the central Rockies is about 30 inches. Two-thirds of this comes in the form of snow, the rest falls in summer rain storms. Ellison's records (1954) show that soil moisture was below the wilting point in subalpine zone soils only once in 15 years. Ronco (1961) found that frequent watering during dry summers did not increase the survival of planted spruce in central Colorado. Summer drought probably does not pose a serious threat to regeneration success in most instances in the central Rockies, but late spring and early summer drought is a serious cause of mortality of seedlings in the southern Rockies.

Soil

Although not much is known about soil requirements for spruce regeneration, Alexander (1958) reported that spruce generally makes best growth on moderately deep, well-drained, silt and clay loam soils developed in place from volcanic and fine sedimentary rocks. Trees on alluvial soils also grow well. An accessible water table is more important than physical soil properties in those situations. Spruce does not make good growth on shallow, dry, coarse-textured sands and gravels; heavy clay surface soils; or saturated soils.

Organic Matter Depth

The depth of organic matter on the seedbed, whether it is in well-organized L, F, and H layers or an accumulation of litter or other debris, may inhibit the regeneration of spruce. Where the depth of organic matter exceeded 2 inches, Roe and Schmidt (1964) found few spruces or lodgepole pines (fig. 9). For spruce, this can be explained by the short first-year root penetration, which is only about 1½ inches in British Columbia (Smith 1955) and western Montana (Roe).[9] It is common to observe countless seedlings on heavy duff layers under spruce stands in the spring, only to find them gone by autumn.

[9] Op. cit., see footnote 3.

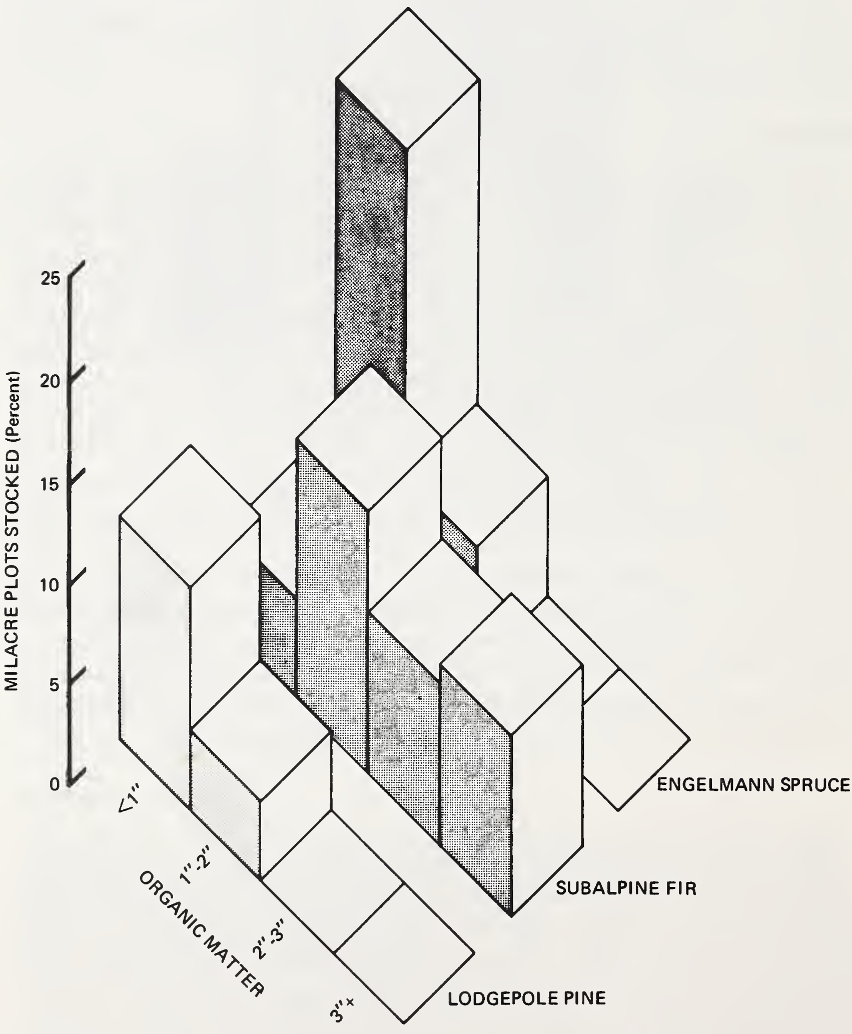

Figure 9.—**Stocking in relation to depth of organic matter (L, F, and H layers).**

Subalpine fir establishment is affected less by depth of organic matter, than is spruce, which may partly explain why subalpine fir is predominant in advance reproduction started beneath overwood (Day 1964, Roe and Schmidt 1964, Alexander 1968).

Rocks

An affinity of seedlings for microenvironments close to large surface rocks was so consistent in the Intermountain Region's survey that it could hardly be considered chance (Roe and Schmidt 1964). The large rocks modify adjacent soil conditions. Rain falling on the rocks drains to adjacent soil. The rocks also cast some shade and reradiate heat slowly at night. Furthermore, larger rocks protect seedlings from animal trampling.

Erosion

High-intensity summer storms and runoff from snowmelt cause an undetermined amount of erosion and seedling loss on mineral soil seedbeds. Erosion has two important effects: (1) Rills and gullies uncover roots of seedlings, and (2) deposited soil buries seedlings. The Intermountain Region regeneration survey showed that many seedlings were destroyed by both scouring and deposition (Roe and Schmidt 1964).

Biota

Disease and Rodents

In one study on the Coram Experimental Forest in Montana, disease and rodents caused from 27 to 42 percent of the total seedling mortality. These losses were early in the growing season—most of the disease loss occurred before July 15. Haig et al. (1941) reported similar damage from rodents for spruce growing in the white pine type. Seedlings were nipped shortly after germination while the seed coats remained attached. Ronco (1967) found that established spruce plantations could be completely devastated by mountain pocket gophers (*Thomomys talpoides* Richardson) as long as 3 to 4 years after planting.

Damping-off fungi also cause serious losses among newly germinated seedlings, especially on seedbeds with a layer of organic matter at the soil surface.

Damage From Large Animals

Grazing and browsing animals kill numerous seedlings. In western Montana, cattle—in one trip through a seedling survival study—trampled and killed 10 percent of the marked first-year spruce seedlings. Seedlings were both buried and kicked out of the ground. The extremely small size of young spruce seedlings makes them especially vulnerable to trampling damage.

Heavy mortality of 2–0 Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings planted in an administrative study on the Payette National Forest[10] was attributed to cattle damage. About 58 percent of the trees planted in furrows and from 20 to 54 percent of those planted in the "berm" adjacent to the furrows

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[10] Op. cit., see footnote 5.

and in scalps, were killed. Since cattle prefer to walk in the furrows, greatest damage resulted in trees planted there.

Ground Vegetation

Grass, forbs, and shrubs may benefit seedlings up to a point (Day 1964, Roe and Schmidt 1964, Alexander 1966). Both shading and mulching may improve some microenvironments by conserving moisture, but root competition for moisture is likely to outweigh the benefits of live shade.

Physiography

Spruce grows over a wide range of physiographic conditions (elevation, aspect, and slope). It grows from as low as 2,000 feet elevation in the northern Rocky Mountains to as high as 12,000 feet in the southern Rockies (Alexander 1958). Roe and Schmidt (1964) point out that in the Intermountain Region, the stocking of seedlings of all species found established subsequent to logging and seedbed treatment showed a high degree of correlation with elevation (fig. 10). As one moves north in the Region and the elevation where spruce grows decreases, regeneration on 3- to 6-year-old cuttings increases, and sites tend to be more hospitable. The total benefit cannot be credited to elevation as such, but rather to a combination of factors associated with elevation and latitude. Generally speaking, spruce sites are best on north and east exposures and on mid to lower slopes.

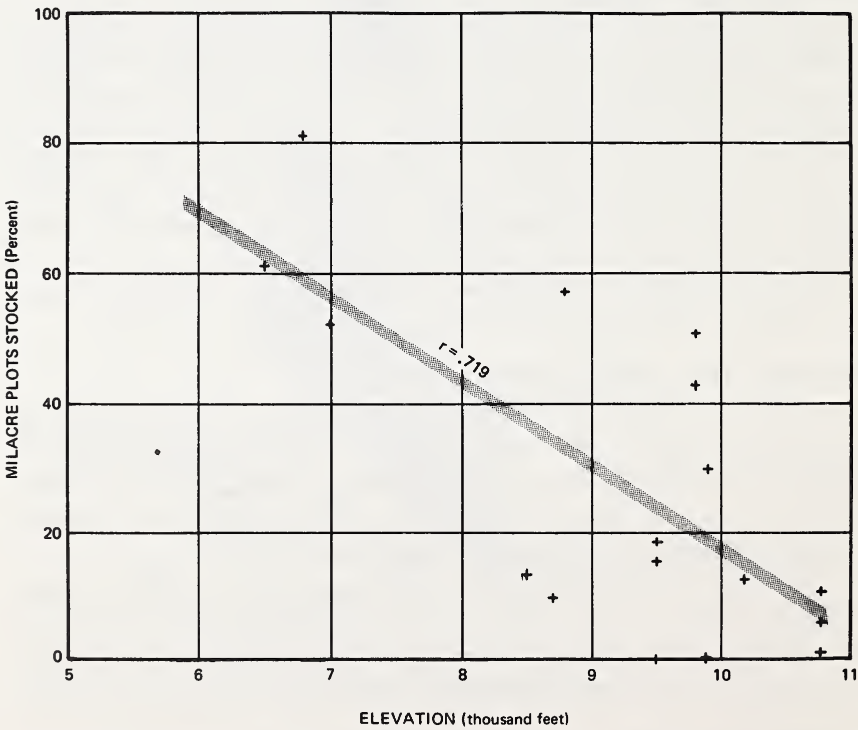

***Figure 10.*—Relation of stocking to spruce seedlings and elevation in the Intermountain Region.**

RECOMMENDED MANAGEMENT ALTERNATIVES

Forest Survey estimates show that approximately 86 percent of the spruce-fir type is in overmature sawtimber stands. These stands offer little opportunity for management because of their advanced age, slow growth, and likelihood of heavy blowdown, especially if partially cut. Furthermore, partial cutting tends to favor subalpine fir regeneration over spruce. Forest managers have most often elected, therefore, to practice some form of even-aged management. Consequently, the discussion of recommended management alternatives will be concerned chiefly with methods that result in essentially even-aged reproduction.

To restock cutover spruce-fir stands, consideration should be given first to the cultivation of existing *acceptable* advanced regeneration, and secondly to inducing subsequent restocking by natural or artificial means.

MANAGEMENT FOR ADVANCED REPRODUCTION

Although many spruce-fir forests have an understory of advanced growth, wide variation in age, composition, quality, and quantity of advanced reproduction requires careful evaluation to determine its potential for further management. The management potential of advanced growth should be determined before cutting is planned. One course of action is followed if the advanced reproduction is to be managed, another if there is no advanced reproduction present or if the manager decides to destroy it and start a new stand.

Initial examination must answer such questions as:

1. How much of the area is stocked with acceptable advanced seedlings and saplings of desirable species? Will that stocking assure a satisfactory replacement stand?

2. Can the stand be logged economically by methods that will save the advanced reproduction?

3. How much of the area will require subsequent natural or artificial regeneration either because the advanced reproduction is absent or will be destroyed in logging?

Criteria for Evaluating Advanced Reproduction

Where local criteria are unavailable, advanced reproduction should meet the following preliminary specifications to qualify as *acceptable* growing stock: (Since there are few data available upon which to predict the growth response of suppressed spruce and fir, these criteria are based largely on our experience and observation).

1. Growing stock must be not more than 80 years old for Engelmann spruce and 50 years for subalpine fir (age measured at breast height).

2. Crown must be of good vigor and extend over not less than 40 percent of total tree height (Roe and DeJarnette 1965).

3. The stem must have good form and have no serious mechanical damage that cannot be outgrown before the end of the rotation.

4. The tree must be free of major defects that will affect future growth. Subalpine fir should be sampled to determine the incidence of heart rot.

5. The stand should contain at least 300 well-established, *acceptable* seedlings per acre, or 150 saplings, of a commercially important species. Stands or portions of stands not meeting those standards should be considered in need of additional stocking.

Precutting evaluation of advanced reproduction should lead to a choice among three alternatives:

1. Cut in such a way that a manageable stocking of advanced reproduction is saved.

2. Destroy the advanced reproduction because heavy removal volume prevents saving it, or there are not enough trees to provide a manageable stand, or it is defective. Plan to regenerate the area with either artificial regeneration, subsequent natural reproduction, or a combination of both.

3. Save portions of the advanced reproduction and supplement it by either artificial regeneration, subsequent natural regeneration, or a combination of both.

If advanced growth is to be managed, then protection and development of established reproduction assumes paramount importance. It involves both careful planning and supervision of the cutting to prevent excessive logging damage. Cultural practices following cutting may be needed to aid development and growth.

Cutting To Save Advanced Reproduction

Mature and overmature trees should be cut to release advanced reproduction and harvest merchantable volume. Seed sources need not be reserved from cutting unless required for fill-in or supplemental stocking. In locations where it is necessary to reserve trees for esthetic purposes or as seed sources, cutting should be directed toward releasing and protecting the advanced reproduction. Trees of low vigor should be removed first. This can be done by identifying condition classes in the stand and removing poorer classes in units of 1 to 5 acres.

Protection of advanced reproduction begins with a well-designed logging plan. Logging equipment must be suited to the terrain. Skidding, movement of equipment, and other logging activity must be rigidly controlled. Movement of tractors and other equipment must be confined to a well-planned layout of skid roads to minimize both soil and disturbance and destruction of advanced growth.

Slash Treatment

Slash treatment should be limited to areas of heavy concentrations as required for protection from fire and insects or the preservation of esthetic values. Furthermore, slash should be treated carefully to avoid unnecessary damage to the advanced reproduction. Fell the tops into openings where possible so that a minimum of work with brush dozers is needed to concentrate the slash for burning in piles. Burning should be confined to the smallest area possible. Turning and traveling in the area with slash disposal tractors should be minimized.

Postlogging Reevaluation

Regardless of how carefully logging and slash treatment are done, a certain amount of damage to the advanced reproduction is inevitable. The area must be checked, in this order, to:

1. Determine the extent of damage to acceptable reproduction.
2. Plan stand improvement measures—cleaning, releasing, and thinning crop trees.
3. Determine the need for fill-in stocking and regenerating nonstocked portions of the cutover area.

Cutover areas should not be considered in an adequate growing condition until the crop trees are free to grow and the necessary fill-in planting or natural regeneration is complete.

MANAGEMENT FOR REPRODUCTION FOLLOWING CUTTING

Regeneration cuttings are made to harvest the timber crop and reproduce the stand. When suitable advanced reproduction is not present, the area must be regenerated by natural or artificial means. Cutting methods, logging plans, and site treatments all should be designed to (1) facilitate seed production and dissemination, (2) promote seedling establishment, and (3) create favorable growing conditions. If natural regeneration fails, then plans must be made to use artificial regeneration.

Clearcutting by groups, patches, and strips is recommended for harvesting overmature Engelmann spruce stands. Those cutting practices may be readily adapted to the multiple-use concept of land management by judicious selection of size and arrangement of cutting units. Requirements for seed dispersal and site preparation will influence the size of cutting unit if natural regeneration is desired. The best seedbed preparation is wasted if the seedbed does not receive sufficient seed; likewise, any quantity of seed is wasted if it does not fall upon a suitable seedbed.

Where esthetic values are of chief concern and where risk of windfall is below average, a shelterwood system can be used. Shelterwood cutting does not cause an abrupt change in the forest. Engelmann spruce regenerates satisfactorily under partial cutting on good mineral soil seedbeds, but the overwood hampers later growth of the seedlings (Roe and DeJarnette 1965). Therefore, plans should be made to remove the shelterwood before reproduction is suppressed.

Scattered windfalls that may occur in partial cuttings sometimes provide a suitable habitat for the rapid buildup of Engelmann spruce beetle populations. Partial cutting should be limited mainly to areas where the risk of blowdown is minimal (Alexander 1964, 1967a). On sites where trees are not windfirm, the manager faces the decision whether to clearcut or to leave the stand uncut.

Seed Source

Clearcut Areas

Cutting must be designed so that the seed from the surrounding timber margin reaches all parts of the cutting unit unless supplementary artificial reforestation

is planned. Effective seeding distance and the seed source dictate the size of the opening.

The two tabulations following this paragraph are guides developed for Intermountain Region conditions (Roe 1967). They are based upon reasonably good seed production data but rather sketchy spruce seedling survival data from the Coram Experimental Forest. They are, however, the best available information. Effective seeding distance, as used in the guides, is defined as the distance to which sufficient sound seed is disseminated to provide for an arbitrary minimum first-year stocking of approximately 40 percent of milacre plots or about 1,200 seedlings per acre on mineral soil seedbeds where competition from understory vegetation has been eliminated and suitable shade and protection from animals is provided.

The number of first-year spruce seedlings established on bared mineral soil on three aspects is shown in the first tabulation:

Aspect	*Seedlings per 1,000 sound seed*
North	34
South	9
West	4.5

The second tabulation shows the estimated maximum effective seeding distance and the resulting sizes of openings that could be made on three aspects—based on 5 years of average seed production (one excellent seed crop may provide as much seed as five average seed crops):

	Basal area in spruce seed trees	Effective seeding distance	Size of square clearcut
Aspect	*Sq. ft.*	*Chains*	*Acres*
North	200	10	40.0
	70 or less	4	6.4
South	200	8	25.6
	70 or less	0	0
West	200	6	14.4
	70 or less	0	0

Based on these effective seeding distances, the following conclusions were reached:

1. Where natural regeneration is desired, the size of the opening must be determined by the quantity of the seed source.

2. Clearcutting for natural regeneration is most likely to succeed on north and east aspects. Clearcutting on south and west aspects is not likely to result in an acceptable stand of new reproduction without a very heavy seed source or planting.

3. When larger openings than those shown in the tabulation are cut, it will be necessary to plant the area beyond the effective seeding distance.

4. Where only a light seed source and poor quality trees can be left, plan to plant the cutover area.

5. Scattered seed-tree groups should not be left except in protected areas on deep, well-drained soils. Experience has shown that scattered seed-tree groups and narrow strips are highly vulnerable to windthrow and may not survive long enough to cast significant amounts of seed (Roe and DeJarnette 1965).

6. Since effective seeding distances are extremely variable between locations, land managers should develop and use their own criteria. The above values were used chiefly for illustration. They should not be applied without modification for local conditions.

Windfall

Guides for minimizing windfall around clearcuttings have been developed in Colorado (Alexander 1964, 1967a). They are summarized below:

1. Keep total cutting boundary perimeter to a minimum by making cutting units as large as reproduction requirements, topography, soil, and stand conditions permit. Larger units, in addition to being more windfirm, permit more flexibility in locating boundary lines.

2. Do not locate cutting boundaries where they will be exposed to accelerated winds funneling through saddles in ridges to the south and west of the cutover area, especially if the ridges are at high elevations. Success in reducing blowdown from that kind of exposure depends upon the ability of the forester who lays out the cutting-unit boundaries to recognize exceptionally hazardous situations.

3. Avoid locating cutting boundaries on ridges or near saddles in ridges, especially ridgetops of secondary drainages to the lee and at right angles to the main drainage when the latter is a narrowing valley with steep slopes. One cutting unit should straddle each ridgetop and extend downslope in both directions for a distance of at least 200 feet. That unit may be cut on uncut. Such an arrangement will avoid leaving a cutting boundary on the top of a ridge.

4. Lay out each unit so the maximum amount of cutting boundary is parallel to the contour or along a road where topography, soils, and stand conditions will permit.

5. Do not lay out cutting units with dangerous windcatching indentations or long, straight lines and square corners in the leeward boundary or in boundaries that are parallel to stormwinds. V- or U-shaped indentations in the boundary can funnel wind into the reserve stand. Long, straight cutting-boundary lines and square corners also deflect the wind and cause increased velocities where the deflected currents converge with others such as a windstream flowing over a crest. Irregular cutting boundaries without sharp indentations or square corners lessen the opportunity for deflection and funneling of air currents.

6. Do not locate cutting boundaries on poorly drained or shallow soils. Trees grown under these conditions are shallow rooted and susceptible to windthrow.

7. Locate cutting boundaries in stands of sound trees. Trees with decayed roots and boles or root systems that were cut or torn during road building or log skidding operations are poor windfall risks.

8. Locate cutting boundaries in immature stands when possible. Young trees are usually less easily uprooted by strong winds.

9. Locate cutting boundaries in poorly stocked stands. Open-grown trees are more windfirm than trees grown in dense stands.

10. Avoid locating cutting boundaries in areas where there is evidence of old wind damage. Old, prelogging blowdowns are additional warning of windfall hazard.

11. Reduce blowdown in areas with exceptionally hazardous windfall potential by locating the vulnerable leeward boundaries where hazards are below average or by eliminating those boundaries by progressive cutting into the wind.

Shelterwood

Shelterwood cutting may be desirable in situations where esthetics or other multiple-use requirements prevent clearcuttings. A seed source distributed over the cutting area insures better seed distribution than clearcutting but at the risk of losing seed trees to windthrow.

A few simple guides follow:

1. Shelterwood cuttings can be used on south and west aspects to provide seed and shade protection if windfall risk is below average (Alexander 1964). When it is necessary or desirable to clearcut south and west aspects, planting is recommended.

2. Trees of good vigor should be left. Select only trees in the upper dominance classes—preferably trees with long, medium-to-wide crowns.

3. A uniform canopy should be left with as little variation as possible in tree height. Avoid making large holes in the canopy.

4. Subalpine firs should be removed unless they have long crowns to shade their holes. Trees with a history of long suppression or crowding should be cut because they are likely to sunscald.

Seedbed Preparation

Mineral soil can be exposed by mechanically scarifying the ground surface, sometimes in connection with slash treatment, or by broadcast burning. Broadcast burning is not recommended in partial cuttings. The thin-barked trees are sensitive to fire damage, and burning around the shallow roots provides courts of entry for wood-rotting fungi. Defective roots may result in excessive windthrow, even in situations where the trees otherwise are windfirm.

Slash Treatment

There are three things to consider when planning the treatment of spruce slash: (1) Slash provides a habitat for Engelmann spruce beetles (in pieces 8 inches in diameter or larger); (2) it provides beneficial shade for germination and seedling establishment; and (3) in heavy concentrations, it obstructs natural seedling establishment.

Burning slash in large concentrations such as windrows or piles often creates enough heat in the soil to inhibit the development of any kind of plant growth

for an unknown period of time. Windrows or piles should therefore be small or narrow, and should cover a minimum proportion of the area.

Broadcast Burning

To be effective, broadcast burning should accomplish certain objectives. It should consume most but not necessarily all of the duff or organic material on the ground, and it should burn hot enough to destroy some or all of the competing vegetation. On the other hand, it should not burn so hot that a deep layer of loose ashes accumulates, the mineral soil changes color, or the rocks fracture. It must leave cull logs, tops, and other large slash to provide shade and protection for soil and seedlings.

Timing of the burn is exceedingly important. The spruce type is generally so cool and moist that times when effective broadcast burns can be achieved are limited. The key to the time to burn is the moisture content of the duff—it must be dry enough to be consumed. If only the surface is dry, a blackened organic layer that inhibits seedling establishment will remain. Fire research must develop criteria for determining when conditions are right for a successful burn.

Mechanical Scarification

Careful mechanical scarification will prepare a satisfactory seedbed if it exposes mineral soil and destroys competing vegetation, but leaves some shade protection. Tractors equipped with brush blades should be used. A complete cleanup job is neither necessary nor desirable. There is a double advantage in not cleaning up too thoroughly. First, residual tops and slash shade the seedbed; second, residual organic material prevents soil erosion. Cut green spruce material over 8 inches in diameter should be removed or treated to prevent the buildup of spruce beetle populations, but true fir material may be left. On highly erodible soils, the duff layer should be removed along the contour, preferably in strips with untouched strips intervening. Some of the larger debris may then be pushed back on the scarified strips for protection, and the dozer walked over it at right angles to the strips, breaking it down. It may not be necessary to burn if the trampled slash meet Regional fuel standards.

MANAGEMENT FOR ARTIFICIAL REGENERATION

Planting

Need and Timing

Good sites should be planted immediately after logging where there is not a manageable stand of advanced reproduction and where local experience has shown that there is little likelihood of obtaining natural regeneration. Areas logged and prepared for natural regeneration that fail to restock in 3 to 5 years need to be plowed or scarified before planting. This should be done before invasion by other vegetation makes the cost of preparing the site excessive. Experience has shown that a minimum goal should be about 300 well-established spruce seedlings in addition to whatever other species may have become established.

Planting cutover areas has several advantages. By growing stock in the nurseries, many of the vagaries of the natural regeneration system are avoided, such as unpredictable seed years, irregular seed dissemination, and the high rates of early seedling mortality. Planting permits better control of stand density, tree distribution, and species and genetic composition of the stand. Planting, unlike natural regeneration, does not impose a restriction on size of cutting units and it removes the necessity of reserving merchantable trees for seed. Furthermore, successful planting may shorten the regeneration period.

There are, however, some disadvantages in planting. Field planting requires close coordination between cutting plans and the availability of planting stock. Delay in planting after logging may increase the costs of site preparation. Costs of surviving seedlings are frequently higher than those of natural regeneration. Close supervision is needed to assure planting of only large, vigorous stock, proper storage and transportation, proper handling of stock from the nursery until planted, and proper planting techniques. Furthermore, planting spruce requires just as much site preparation as natural seeding. Many planting failures in the Rocky Mountains can be traced back to one or more of the disadvantages mentioned above.

In some problem areas in the Rockies, plantations seem to fail despite the best efforts. In these areas, special research must be carried out to determine causes of mortality and to determine measures that will correct the situation.

Site Preparation

The objectives of site preparation for planting should be to (1) remove competition from other vegetation and (2) assure that seedling roots will be in contact with mineral soil having a relatively stable supply of available moisture.

Slash should be treated to eliminate concentrations and leave moderate amounts evenly scattered over the area: Areas may be broadcast burned to prepare sites where there is no manageable advanced regeneration. Logs not consumed by fire provide shade for planted trees. Machine-pile slash on areas where fill-in planting is necessary to supplement advanced or subsequent natural reproduction. Avoid excessive cleanup because dead material is needed for shade, but at the same time, reduction of duff and competing vegetation is essential to provide adequate planting spots.

Planting Stock and Methods

Plant the size and age of stock found most suitable by local experience. The quality of the nursery stock varies with nurseries, and local tests of age and size classes are desirable.

Spruce planting stock should be given exacting care. Lift the trees while they are dormant, and plant them as soon as possible after they are lifted. Planting trees which have broken dormancy before lifting often fails. If necessary, hold the trees in cold storage at about 33° F. and 90 percent relative humidity whenever there will be delays between lifting and delivery to the planting site.

Selecting the proper planting spots such as the east or north (shady) sides of logs, chunks, and surface rocks aids seedling survival. Planting by hand

enables the planter to select good spots. The deep hole method is recommended because it provides enough room to properly place and spread the large root system characteristic of good spruce planting stock.

Plantation Management

New plantings (or seedlings) should be protected from trampling by livestock. This may require temporary adjustment of grazing allotments or, in some cases, fencing until the seedlings become well established.

New plantings should also be protected against rodents (Ronco 1967). Sample the rodent populations on areas that are scheduled for planting or that have been planted, and, if the populations are large, provide controls until the seedlings become established.

Care of established plantations is beyond the scope of this paper and will not be discussed here.

Seeding

Direct seeding has much to recommend it. Historically, however, there have been many more failures than successes. Therefore, a word of caution is in order. Schopmeyer and Helmers (1947) were moderately successful in the northern Rocky Mountains when spruce was fall sown in carefully prepared spots, protected from rodents, and located on good sites (north slopes). Seeding on severe sites failed. Other experience has been variable. Successes have been achieved on good sites and in wet seasons. However, dismal failures have been experienced in dry years or on poor sites. Until more reliable techniques have been worked out, direct seeding of Engelmann spruce is not recommended as a general practice except on the most favorable sites.

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